

Tropical Atmosphere Ocean (TAO) Array

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1. PROJECT SUMMARY

FY 2006 funding was expended to maintain the Tropical Atmosphere (TAO) array as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate." TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). TAO/TRITON supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on El Nino/Southern Oscillation (ENSO). Management of the array is consistent with the "Ten Climate Monitoring Principles." Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). Web sites containing comprehensive information on both programs can be found at <http://www.tao.noaa.gov/> or <http://www.pmel.noaa.gov/tao/>. This report summarizes the progress and accomplishments of the TAO project in FY2006. In FY 2006, there were a lot of progress and achievements for the TAO transition from PMEL to NDBC, which are also summarized in this report.

2. FY 2006 PROGRESS

2.1 TAO/Triton Array

2.1.1 Background

FY 2006 was the sixth full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E to 138°W. JAMSTEC added three moorings along 130°E for its own purposes in FY 2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web (<http://www.tao.noaa.gov/> or <http://www.pmel.noaa.gov/tao/>).

2.1.2 TAO Project Highlights

At present, TAO/TRITON data indicate weak El Niño or neutral conditions in the tropical Pacific. Forecast models, many of which depend heavily on TAO/TRITON data for initialization, suggest that near neutral conditions will continue into early 2006.

2.1.3 Field work

PMEL is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines and a nearby subsurface ADCP mooring is deployed. An ADCP mooring is maintained by JAMSTEC at 0°, 147°E. During the past year, the TAO Project deployed 65 ATLAS moorings and 5 subsurface ADCP current meter moorings in the tropical Pacific. The number of ATLAS deployments exceeds the number of ATLAS sites

in the array because of mooring system failures or losses during the year, because one site (the equatorial current meter mooring 140°W) was turned around on a 6-month rather than 12-month schedule for research and development purposes and because cruise schedules are such that some moorings are deployed for slightly shorter than their 12-month design lifetime.

2.1.4 Ship Time and Sea Time

In FY 2006, 256 days at sea were required (222 days on the Ka'imimoana and 34 on the Ron Brown) to support the TAO portion of the TAO/TRITON array. PMEL participated in 446 person-days at sea (number of people times days at sea). For comparison, during FY 2005, 255 days at sea (220 days on the Ka'imimoana and 35 on the Ron Brown) were required and PMEL participated in a total of 620 person-days at sea.

As part of the TAO Transition, NDBC participated in 386 person-days at sea (number of people times days at sea) for getting familiar with TAO operations and in support of TAO field work. The 386 days were both government and contractor personnel as well as engineers and technicians.

2.1.5 Data Return

Percentage real time data return for primary TAO variables integrated over all 55 sites for FY 2005 was as follows:

| | AIRT | SST | T(Z) | WIND | RH | ALL |
|---------|------|-----|------|------|----|-----|
| FY 2006 | 91 | 86 | 83 | 82 | 87 | 84 |
| FY 2005 | 89 | 91 | 92 | 86 | 87 | 91 |

The main reason for the lower overall percentage in FY2006 is because of the vandalism (as discussed in Section 2.4). For examples, the percentages of the two most vulnerable lines on vandalism 95W and 110W line were 76% and 74%, respectively. In FY 2006, 14 sites (out of 55 sites) had the percentages lower than 80%, and seven of them were from 95W and 110W lines (7 out of 14 sites in the two lines).

In addition, FY2006 was the first year that data from the point-source current meters were reported in real time on the four ADCP sites (i.e., TAO moorings next to the ADCP moorings). Totally, there were 18 point-source current meters at various depths (i.e., 5 at 0-110W, 5 at 0-140W, 4 at 0-170W, and 4 at 0-165E), based on the TAO funded requirements. The data return percentage for the current meter in FY2006 was 57.7%. We will continue to monitor and report this new measurement in the future.

2.1.6 Shipboard Measurements

CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the Ka'imimoana and Ron Brown. These data are an integral part of the TAO Project, providing in situ calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

A total of 299 CTD casts were made on TAO cruises in FY 2006, which was a decrease over FY 2005 (407). The decrease in number of CTDs was caused primarily by the ship being diverted from its normal track on several cruises due to breakdown of ships

equipment, medical emergencies, and recovery of moorings which had drifted from their original location. The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii. Underway sea surface salinity measurements are processed at PMEL, and then forwarded regularly to the IRD laboratory in Noumea for distribution (by CD-ROM) with other sea surface salinity data (<http://www.ird.nc/ECOP/siteecopuk/cadres.htm>).

2.1.7 Guest Investigator Research Projects Using TAO Moorings and TAO Cruises

The primary mission of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of the NOAA Ship Ka'imimoana is to service buoys of the TAO/TRITON array. However, the TAO Project Office actively promotes use of the Ka'imimoana and, when it is used for TAO cruises, the Ron Brown for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time or for a limited number of cruises. An ongoing project is either planned or has been onboard already for several years. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY 2006 (Project, Principal Investigator, Institution (Ship):

Underway CO₂, Richard Feely, NOAA/PMEL (KA and BROWN)
Turbulent flux measurements and wind profiler, Chris Fairall and Jeff Hare, NOAA/ETL (BROWN)
Carbon cycle, Michael Bender, Princeton University (BROWN)
Dissolved Inorganic Carbon (DIC) Analysis, Andrew Dickson, Scripps Institution of Oceanography (KA)
Argo float deployments, Greg Johnson, PMEL (KA)
Global Drifter Program, Robert Molinari, NOAA/AOML (KA and BROWN)
Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)
CO₂ moorings, Chris Sabine, NOAA/PMEL (KA)
Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)
Haruphone mooring recoveries/deployments, Robert Dziak, NOAA/PMEL (BROWN)
Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)
Underway pO₂/pN₂- Gas Tension device and O₂ probe, Craig McNeil, University of Rhode Island (BROWN)
Nitrate and O₂ isotope analysis, Patrick Rafter, Scripps Institution of Oceanography (KA)
Equatorial Box Project, Michael Behrenfeld, Oregon State University (KA)
Microstructure Chipod development, James Moum, Oregon State University (KA)
Nutrient Samples, Cathy Cosca, PMEL (KA)
CTD program, Greg Johnson, PMEL (KA and BROWN)

b. One-time or limited-term ancillary projects on TAO cruises for FY 2006 (Project, Principal Investigator, Institution (Ship):

Lagrangian Float, Ren-Chieh Lien, Eric D'Asaro, University of Washington, (KA)
PICO Buoy test deployments, Chris Meinig, PMEL (BROWN)
Moored Fluorometer deployments, Pete Strutton, Oregon State University (KA)

2.2 TAO Project Web Pages

In FY06, the TAO Project continues to maintain the content and functionality of two web sites: one at NDBC (<http://tao.noaa.gov/>) and one at PMEL (<http://www.pmel.noaa.gov/tao/>). These sites provide easy access to TAO/TRITON data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays.

For FY 2006, NDBC TAO web site received 2,441,778 hits and PMEL TAO site received 22,699,591 hits. So, the total hits from both web sites are 25,141,369. Also during FY 2006, a total of 301,002 TAO data files were delivered to end users: 28,673 files from NDBC web site and 272,329 from PMEL web site.

As of FY2006, NDBC became the official TAO data center and NDBC's TAO web site is the official TAO website after one year of end-to-end parallel testing. The parallel testing has demonstrated the successful transition of the TAO IT and Quality Control functions with the agreement rates for all categories met or exceeded the agreement criteria (i.e., 95% or 99%) of the test plan. Please refer to the "TAO End-to-End Test Plan" and "TAO Transition Information Technology and Quality Control Parallel Test Final Report" for more details.

2.3 Operational Use of TAO/TRITON Data

TAO/TRITON data are distributed via GTS to national and international operational centers, such as NOAA's National Centers for Environmental Prediction and the Department of Defense's Fleet Numerical Meteorology and Oceanography Center. Within NOAA, these data are used routinely in climate forecasting and analyses. The data are also used for operational weather and Pacific tropical cyclone forecasting. Weekly ftp transfers to NCEP, ceased in April 2006 at NCEP's request. TAO data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, [barometric pressure], and sea surface temperature. The National Core Processing Center for Multi-Channel Sea Surface Temperature (MCSST) uses TAO/TRITON and PIRATA sea surface temperatures distributed via the GTS to perform validation and improvement to the processing algorithms for MCSST. TAO/TRITON and PIRATA are the only moored buoys used for MCSST validation. Daily averaged subsurface temperature and salinity data are also transmitted on the GTS. The Global Temperature-Salinity Profile Program (GT/SPP) collects the GTS provided subsurface temperatures and salinities and makes them available in real-time via NOAA's National Oceanographic Data Center web site.

2.4 Vandalism

Vandalism continues to plague portions of the TAO/TRITON arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western equatorial Pacific. In addition to partial mooring hardware and instrumentation losses, 7 complete moorings systems were confirmed lost in the Pacific in FY 2006 due to the effects of vandalism.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies,

fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP.

2.5 Public Service

PMEL TAO Project Director serves on the International CLIVAR Pacific Panel and Global Synthesis and Observations (GSOP) Panel and the International CLIVAR/GOOS Indian Ocean Panel (IOP). He is a member of the PIRATA SSG. He is a member of the JCOMM Observations Coordination Group, chairs the Tropical Moored Buoy Implementation Panel (TIP) which is an action group of the Data Buoy Cooperation Panel (DBCP), and is a member of the OOPC/CLIVAR OceanSITES Working Group. McPhaden serves as past president of the Ocean Sciences Section of the American Geophysical Union and is a member of the Bulletin of the American Meteorological Society editorial board.

NDBC continues to represent the North Pacific Data Buoy Advisory Panel (DPDBAP). This panel is interested in data buoys located in the North Pacific – and the membership includes Canada, China, Japan, Korea, Mexico and the United States. NDBC served as a co-host, with the NOAA Office of Global Programs (OGP), to the 22nd Session of the Data Buoy Cooperation Panel (DBCP) and the 26th meeting of the Joint Tariff Agreement (JTA) that was held in La Jolla, California. NDBC currently chairs the DBCP Drifter Evaluation Subgroup and is developing the DBCP's "Best Practices and Standards" booklet for quality control and assurance of moored buoy data.

NDBC Chief Scientist serves as one of the U.S. representatives to the Ocean SITES program of which selected TAO and PIRATA stations are critical components. He also serves as a U.S. representative to the PIRATA Resources Board, and is actively involved in the PIRATA effort including a working group to identify national contributions to PIRATA. Participated in PIRATA 11 and 12 meetings.

The PMEL TAO Project Manager represents the Tropical Moored Buoy Implementation Panel at the JCOMM Data Buoy Cooperation Panel (DBCP), and serves on the OceanSITES Data Team. He attended the DBCP meeting in October 2005 (Buenos Aires), a JCOMM Workshop on Real Time Metadata in February 2006 (Reading, UK), the first OceanSITES Data Team meeting in March 2006 (Honolulu), a NOAA/SEACORM Workshop on "*Use of Ocean Observations to Enhance Sustainable Development - Training and Capacity Building Workshop for the Eastern Indian Ocean*" in June 2006 (Bali, Indonesia), and Oceans 2006 in September 2006 (Boston).

NDBC TAO Project Manager visited Japanese Agency for Marine-Earth Science and Technology (JAMSTEC) and briefed JAMSTEC's TRITON team about TAO transition and technology refresh. During his visit, JAMSTEC briefed him and provided information to him about the newly-developed mini-TRITON buoy. He also attended Oceans 2006 Conference in September 2006 (Boston) and briefed the status of TAO transition and technology refresh during his presentation of "Technology Refresh of NOAA's Tropical Atmosphere Ocean (TAO) Buoy System".

Given the proximity of NDBC's new hurricane buoys to the PIRATA array, NDBC, in consultation with the PIRATA Science Steering Committee, has begun to upgrade stations 41040 and 41041 with additional observations to enhance their usage as a climate resource in conjunction with PIRATA. In the second year of this effort, the NDBC Observations Supporting PIRATA (NOSP) project added temperature and salinity profiles and 10m current measurement with a companion mooring near 41041. This adds to the rain and solar radiation efforts of the prior year.

2.6 TAO Transition FY 2006 Accomplishments

In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service instructed the directors of PMEL and NDBC to develop a plan for transferring PMEL operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program Review Team that TAO mooring operations be consolidated with those at NDBC. After several iterations, the Deputy Administrator of NOAA formally approved a TAO transition plan. The TAO Transition is being executed in accordance with the approved TAO Transition Plan of August 31, 2004, and yearly Work Plans.

FY 2006 TAO Transition efforts focused on four areas: (1) completion of TAO data and IT transition and NDBC's TAO site became the official TAO web site, (2) NDBC's familiarization of TAO operations and readiness of FY07's cruises, (3) development and testing of the TAO refreshed buoy system which to replace obsolescent components and sensors, and (4) development of new TAO IT/data system for the refreshed TAO buoy systems (more real-time data via Iridium satellite system).

For the TAO data and IT transition, NDBC accomplished the following goals in FY 2006:

- Completed the TAO End-to-End Test with satisfied testing reports.
- Completed the one year Parallel Testing for both real-time data and delayed mode data.
- Added Assorted Plots per community user requests.
- Published the TAO Daily Status web pages to the public.
- Completed the version control of all TAO software and enable the Configuration Management (CM) for TAO data systems.
- Completed DAC QA/QC Procedures and SOPs for TAO data monitoring.
- Trained the DAC personnel and integrated the TAO data monitoring and quality control into the NDBC DAC operational workflow.
- Started visual data analysis of real-time current meter and conductivity data.
- Developed or enhanced the capabilities of processing delayed mode rainfall data, Sontek current meter data, and ADCP profile data.
- Integrated the delayed mode data processing into the NDBC DMAC operational workflow.
- NDBC TAO web pages were updated with QA/QC technical information from the NDBC Data Assembly Center.

In order to smoothly take over all TAO field operations in FY07, NDBC sent technical people (two people most of the time) to each of the FY06 cruises (both the Ka'imimoana and the Ron Brown). PMEL and NDBC met a few times and communicated via e-mails

and phone calls to discuss various inventory and logistical support during TAO transition. In FY 2006, NDBC started to purchase and to prepare many items for FY07's cruises.

For the TAO refresh buoy system, NDBC accomplished the following tasks:

- A new data logger AMPS was fully developed and tested for TAO.
- A new layout of electronics and batteries was designed with the same form factors of the external tube.
- The Commercial-Off-The-Shelf (COTS) underwater sensors (i.e., temperature, conductivity, and pressure sensors) were adopted and tested.
- A new design of the inductive modem (IM) coupler was adopted and integrated.
- Preliminary Design Review (PDR) and Critical Design Review (CDR) on the design of the refreshed buoy were conducted.
- Two prototype TAO refreshed buoys were integrated and tested in the lab.
- A prototype refreshed buoy was deployed in the Gulf of Mexico for field testing. Minor problems on the AMPS and IM connection were found and corrected. More testing on the prototype refreshed will be conducted in FY07.

During FY 2006, NDBC accomplished the following goals for data/IT part of the TAO refresh:

- Developed the NDBC refreshed TAO database.
- Developed new TAO real-time processing systems for NDBC AMPS payloads.
- Developed new NDBC DAC Management Console.
- Developed new TAO data display and data delivery web pages.

In addition to the technical management aspects of TAO, NDBC provided Project Management of the TAO transition to include numerous schedule details and updates, status briefs and reports, contract management, and coordination between PMEL and NDBC.